

LightMat: Development of a Novel Magnesium Alloy For Thixomolding® of Automotive Components

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Overview

Timeline/Budget

- Program start: Feb. 2020
- Program end: Feb. 2022

Barriers

- Mg alloys have insufficient ductility and energy absorption for crash protection
- Lack of low-cost, environmentally friendly magnesium production capability, atmospheres used for handling molten magnesium involve greenhouse gas subject to safety concerns
- Corrosion protection required for new alloys
- Long development time of advanced materials

Budget

- Total Project Funding: \$ 1 M
 - DOE: \$500,000
 - Industrial cost share: \$500,000
- 40% Complete

Partners

- **Lead National Laboratory**
 - Oak Ridge National Laboratory (ORNL)
- **Industrial Partners**
 - FCA US LLC (Stellantis)
 - Leggera Technologies

Relevance

- Reducing the weight of a conventional passenger car, battery electric and heavy-duty vehicles by 10% using lightweight Mg alloy components will result in a 6%–8% improvement in fuel economy
- Availability of Mg alloy components with improved energy absorption and ease of manufacturing will reduce barriers for use and accelerate automotive lightweighting
- Alloys with optimum combination of ease of processing, strength, and ductility are needed

Objectives:

- Develop a Mg alloy with **ease of processing** in thixomolding®
- New Mg alloy should achieve desired combination of strength and ductility in thixomolded® components



Current Wrangler Spare Tire Carrier
(Thixomolded AM60B)



Background: Thixomolding® Process

- Casting method where the alloy is
 - Heated to 560° to 600° C to the solid + liquid region and sheared until it reaches “dough-like” consistency
 - Injected into a mold
 - Duration of the injection process ~ 0.03 seconds
 - Cycle time - 20 to 45 seconds.
- **Advantages**
 - More uniform structure and lower porosity and/or cavity-free compared to die casting due to **laminar flow** front
 - Fast freezing/cooling rates of > 100°C/s for molded parts
 - Fine grain size and reduced eutectic size
 - Higher ductility and fatigue strength
 - Long die life, due to 80°C cooler metal temperatures than die casting
 - Environmental friendliness, with no open foundry, no SF₆ gas, no sludge or dross - with worker comfort and safety
 - Higher process yield, less scrap
 - Flexibility in part design, down to 0.7 mm thickness

Viscosity decreases with shear rate*

Viscosity Pa s	10 ⁻⁵	10 ⁻⁴	10 ⁻³	10 ⁻²	10 ⁻¹	10 ⁰	10 ¹	10 ²	10 ³	10 ⁴	10 ⁶	10 ⁸	10 ¹²
Non-Metallic Materials		Acetone	Water	Olive Oil	Yogurt	Glycerin	Honey, Ketchup	Chocolate syrup	Molasses, Bitumen				Molten Glass
Metallic Alloys			Liquid Metals	Semi-solid alloys at fs=0.4									
				$\dot{\gamma} = 200s^{-1}$					$\dot{\gamma} = 0.001s^{-1}$				

*Adapted from F. Czerwinski, Magnesium Injection Molding, Springer, 2008

Schematic of Thixomolding® process

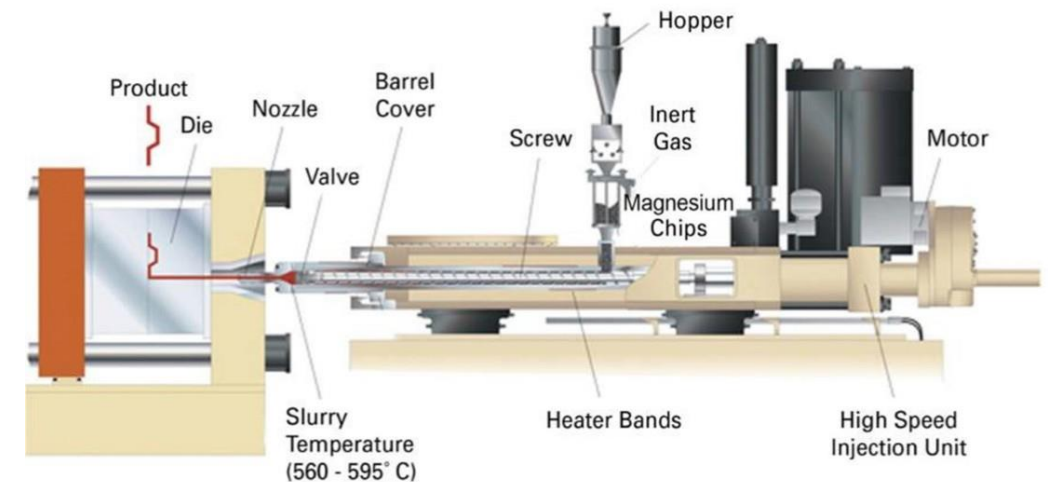


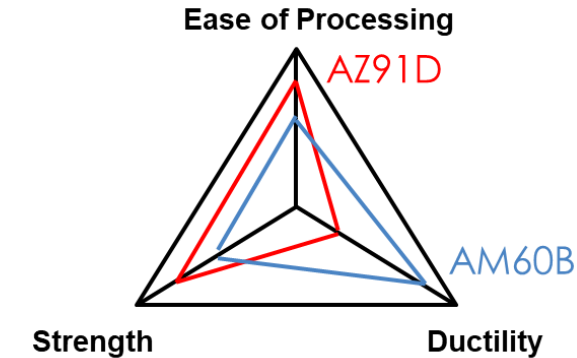
Figure courtesy Leggera Technologies

Existing Die Casting Alloys Trade Ease of Thixomolding® For Mechanical Properties

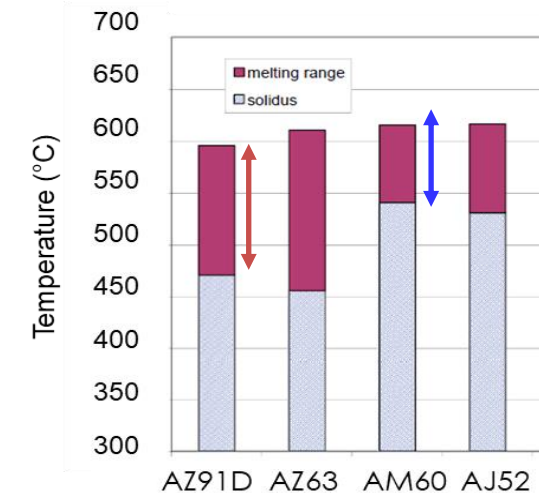
- Existing alloys have been primarily designed for injection molding in liquid state (for die casting)
- Components thixomolded® with die casting alloys do not have balanced properties
 - AZ91D has good processing characteristics, high strength, but poor ductility
 - AM60B has good ductility but needs improvement in strength and processing characteristics
- Need to design new alloys with balanced properties for thixomolded® components
 - Increase liquid + solid range to have good control on solid fraction at injection temperature
 - Target microstructure to increase ductility while maintaining or improving strength (e.g. achieve fine grain size)
 - Maintain/improve corrosion resistance

Composition and properties of thixomolded alloys

Alloy	Mg	Al	Zn	Mn	Yield Strength (MPa)	Elongation
AM60B	Bal	6	0.2	0.3	121	16
AZ91D	Bal	9	0.7	0.3	158	6

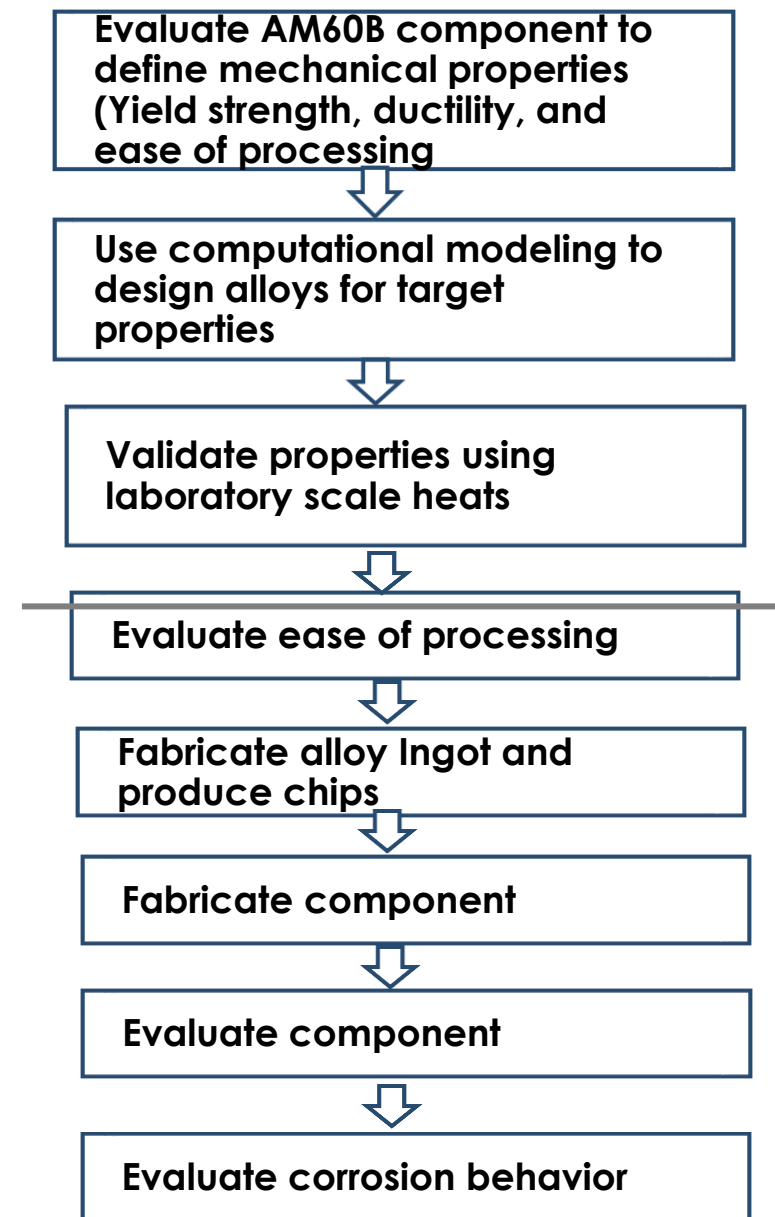


Melting range of AZ91D is wider and solidus is lower than AM60B*



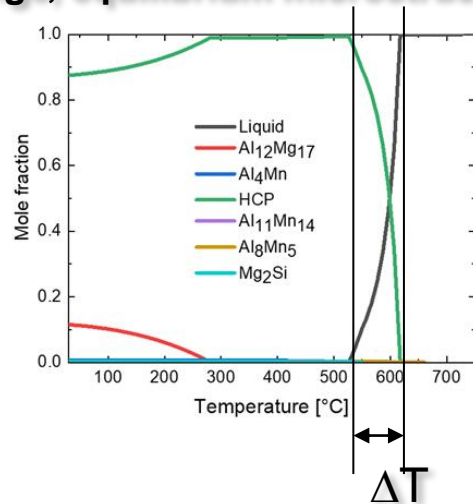
Approach

- Task 1 : Establish required/desired properties using study of baseline component
- Task 2: Alloy development using computational modeling
- Task 3: Alloy ingot and chip production
- Task 4: Produce component tooling
- Task 5: Component production
- Task 6: Material characterization and Computer-Aided Engineering (CAE)
- Task 7: Component evaluation

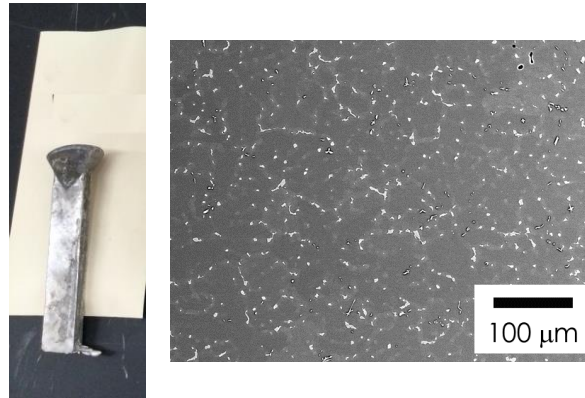


Alloy Design Balances Solidification Characteristics with Mechanical Properties

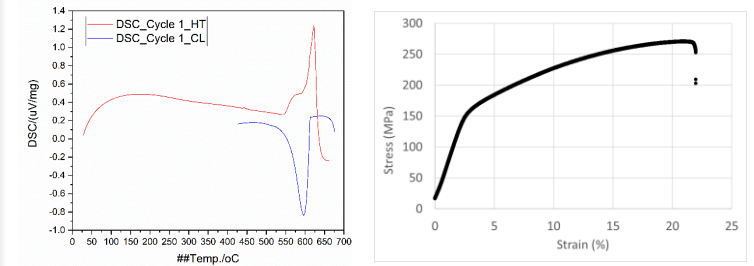
Alloy design using thermodynamic modeling
(Liquidus, solidus, solidification range, equilibrium microstructure)



Laboratory Scale Heats
Microstructural Evaluation



Differential Scanning Calorimetry,
Mechanical Properties



Iterate

FY20-FY21 Milestones

Month/ Year	Milestone Description	Status
June 2020	Establish desired material properties	Completed
Dec. 2020	Fabricate laboratory scale heats of promising, modified alloys	Completed
Mar. 2021	Initial down-selection of compositions with good tensile properties and corrosion behavior with improved characteristics for thixomolding®	Completed
June 2021	Produce alloy ingot and chip	On-track
Sept. 2021	Produce components using down-selected alloy	On-Track

Material From Different Regions of Baseline Component Spare Tire Carrier Was Evaluated For Microstructure and Mechanical Properties

- Base Thixomolded[®] Component
 - Spare tire carrier fabricated by Leggera Technologies using AM60B
- Small sections of material were removed from different locations
- Microstructure and mechanical properties were evaluated

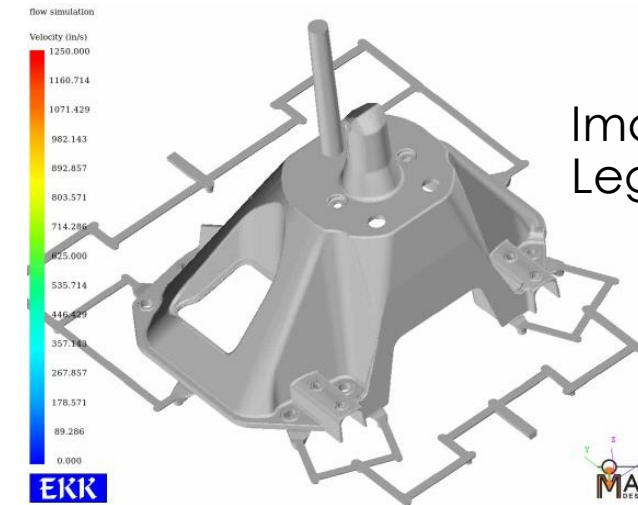
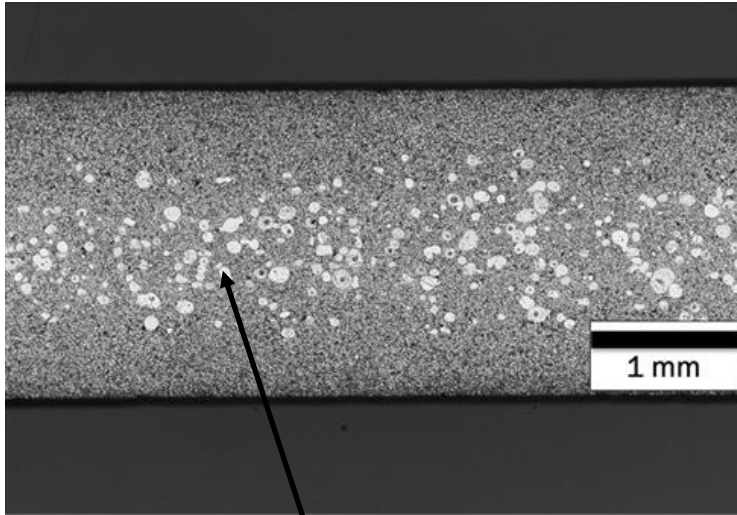


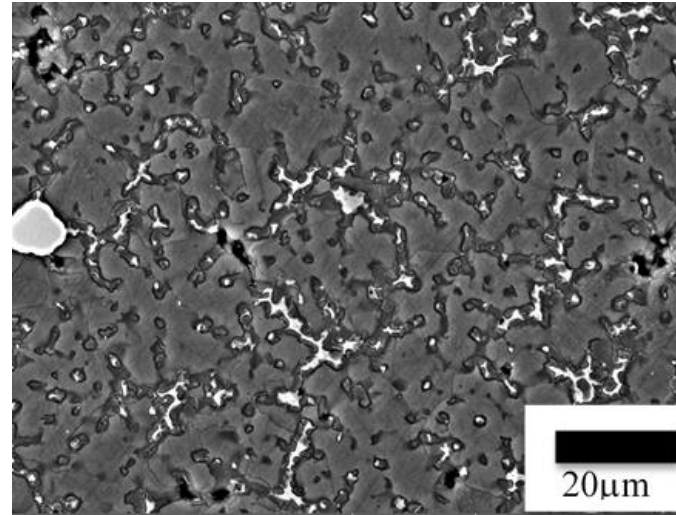
Image courtesy:
Leggera Technologies



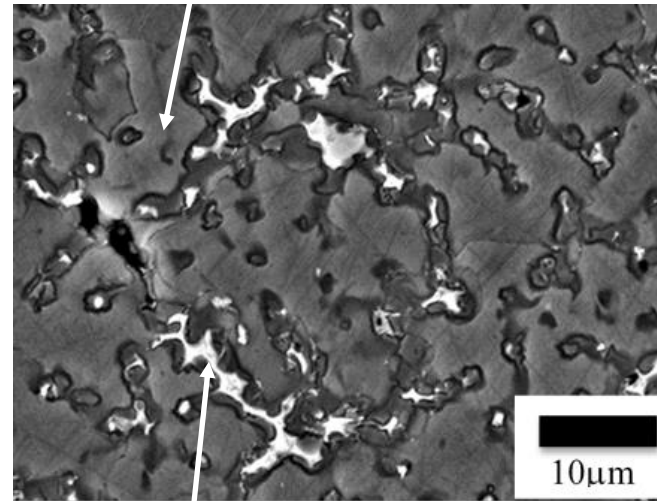
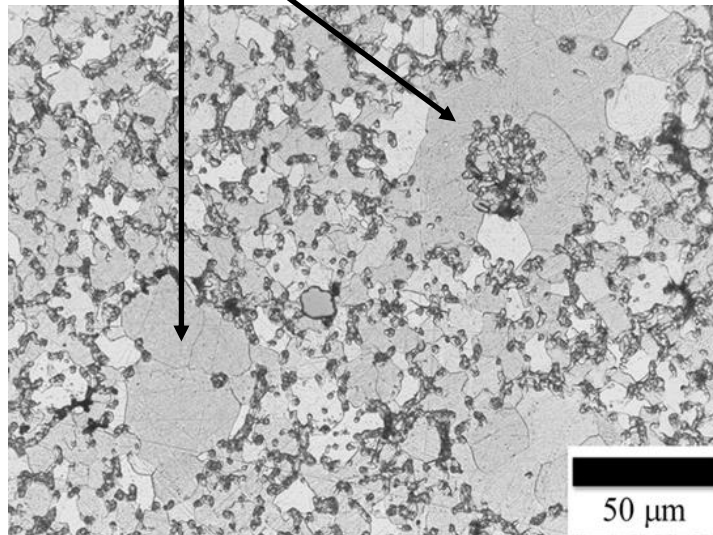
Microstructure and Mechanical Properties Have Been Evaluated To Establish Baseline



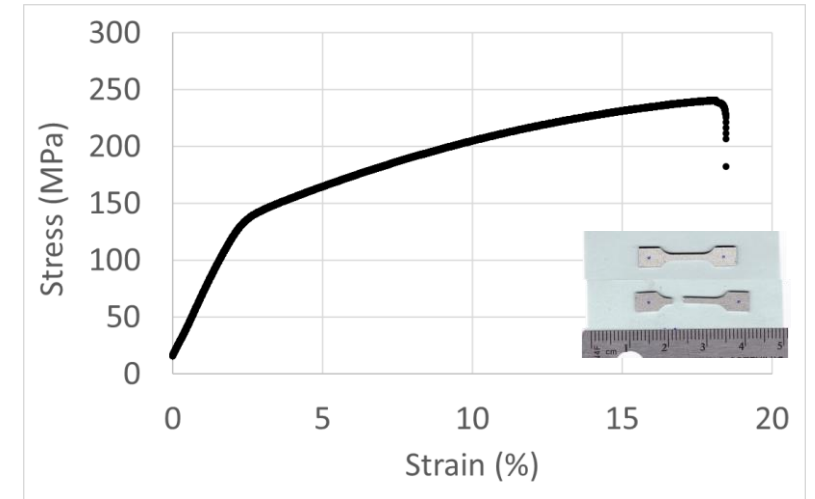
Primary α -Mg nodules



Proeutectic α -Mg

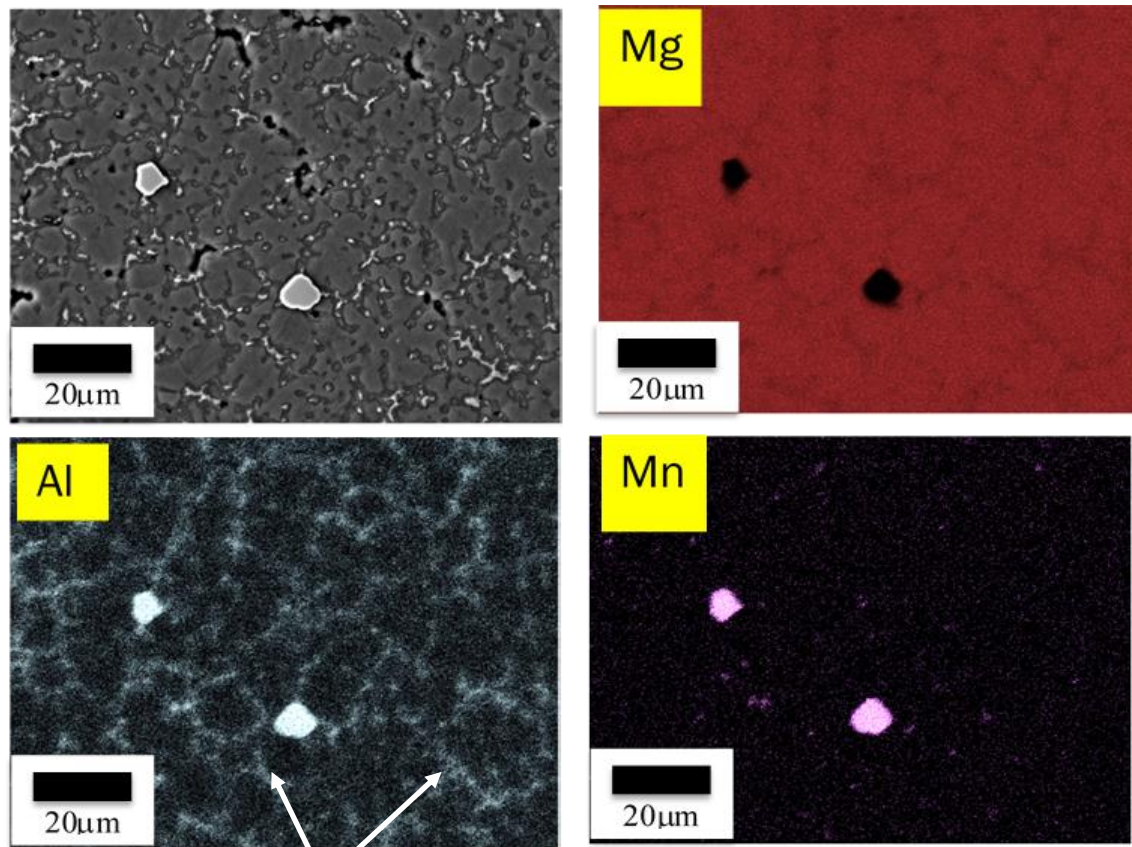


Eutectic $\text{Al}_{12}\text{Mg}_{17}$

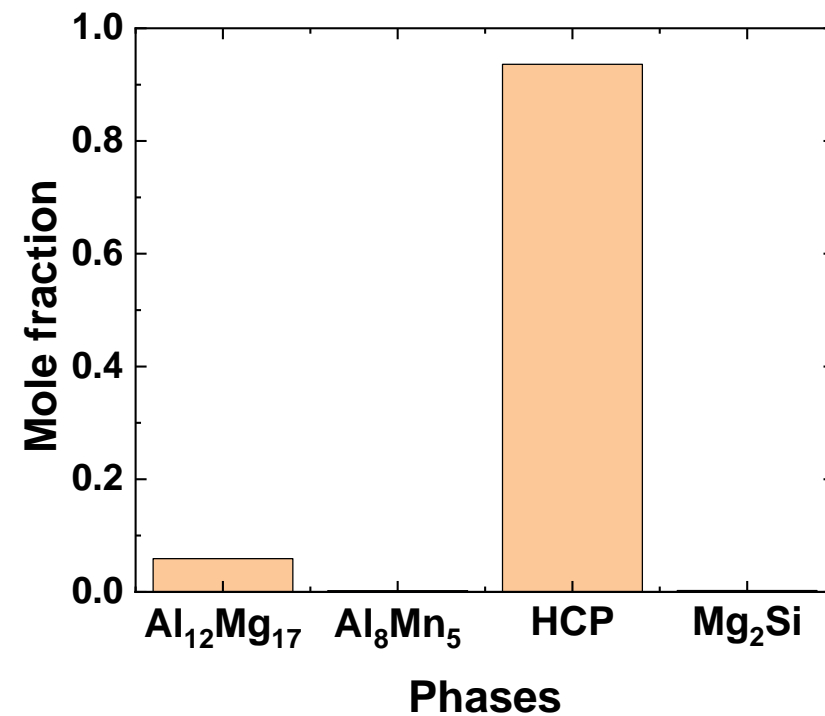


Yield Strength = 131 MPa
Elongation to failure = 18.4%

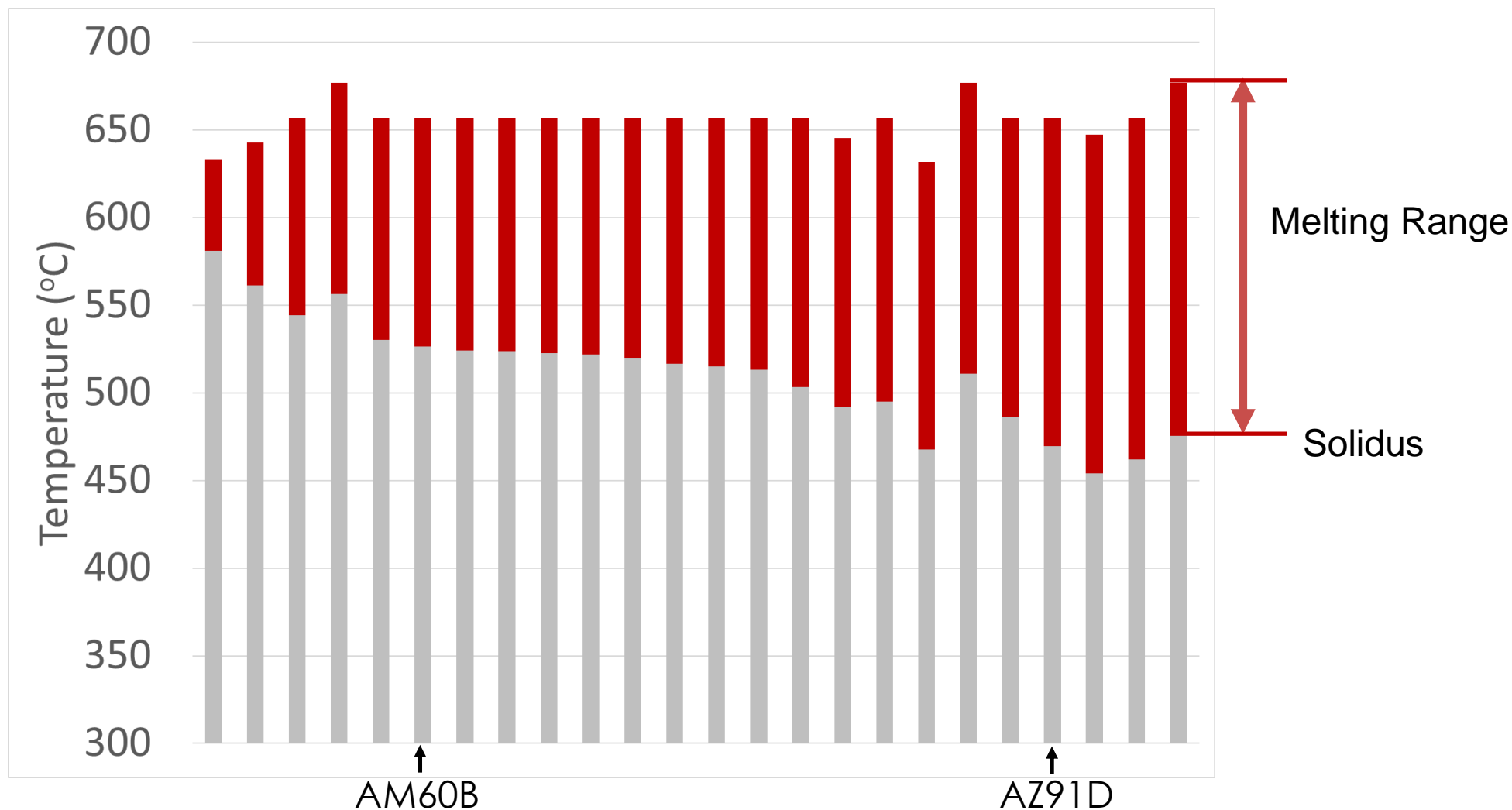
Phase Content After Solidification in AM60B Consistent with Predictions



Al- rich Interdendritic
($\text{Al}_{12}\text{Mg}_{17}$) Phases



Computational Modeling Used to Identify New Alloys with Melting Range Comparable to AZ91D



Laboratory Scale Heats Have Been Cast at ORNL

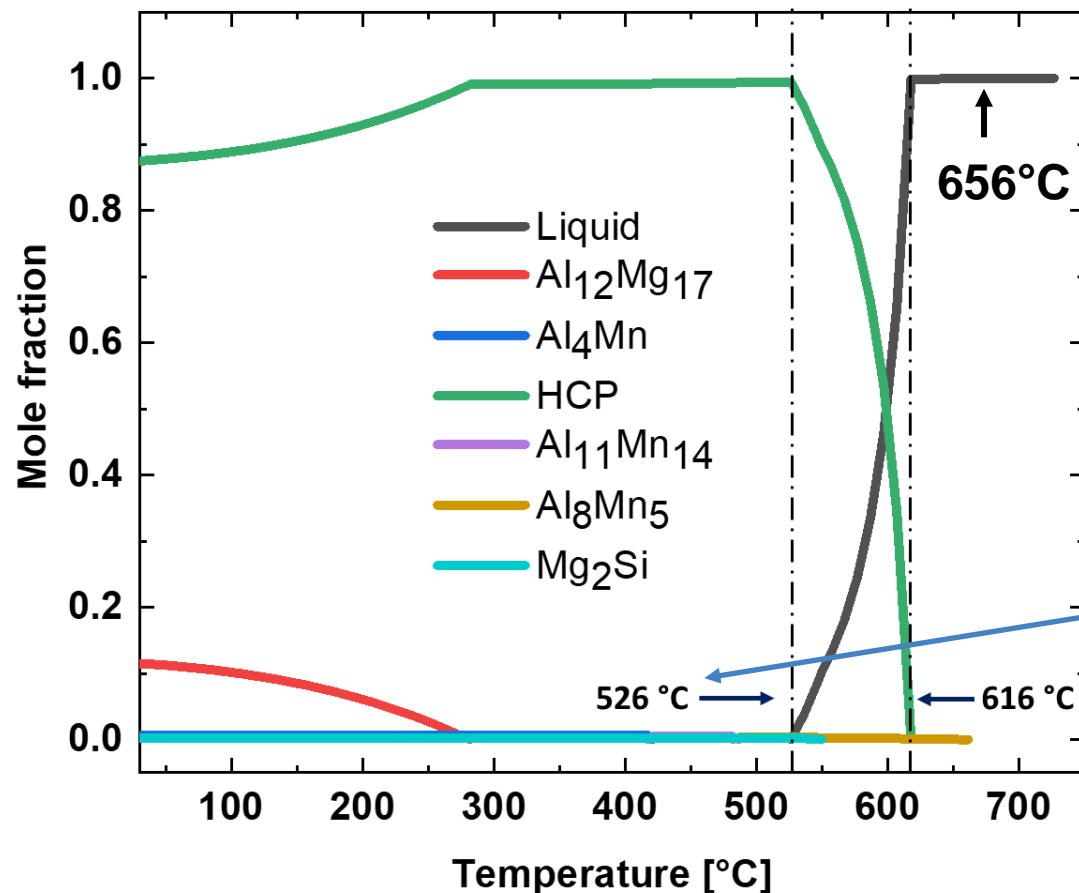


$\frac{1}{2}$ " X1" X5" ingots cast at ORNL

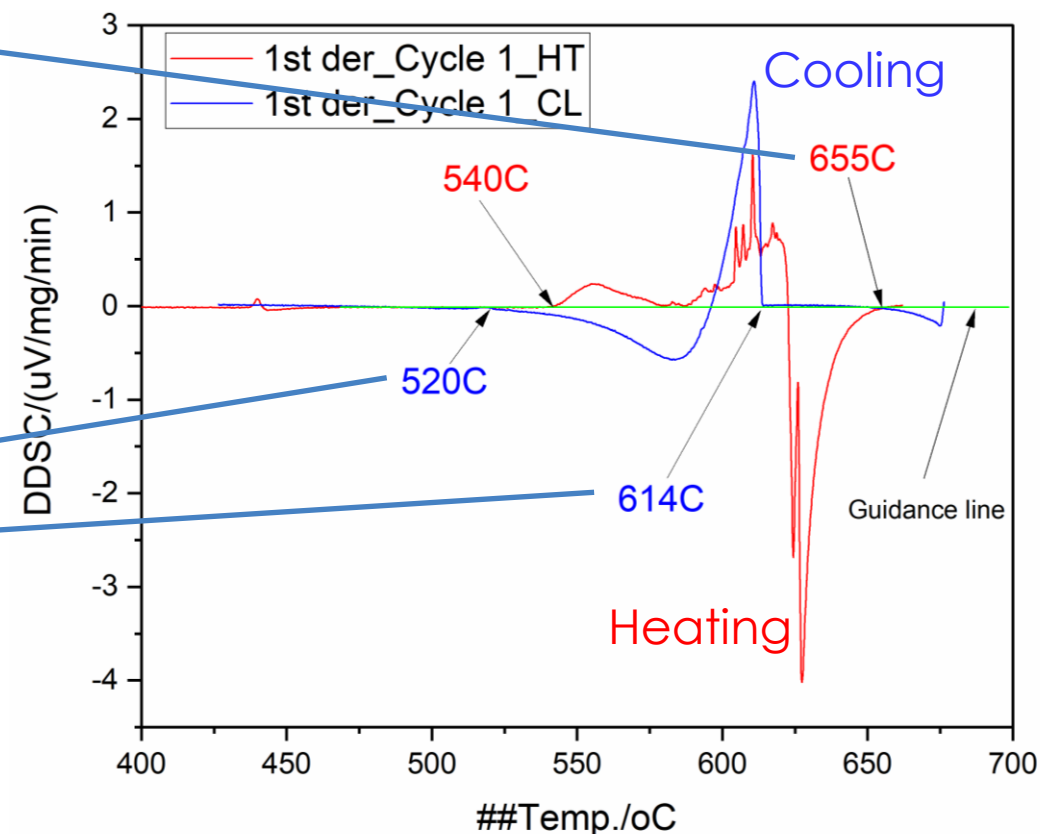


Thermodynamic Predictions for Liquidus and Solidus Are Being Validated Using Differential Scanning Calorimetry (DSC) Measurements

ThermoCalc™ Predictions for AM60B

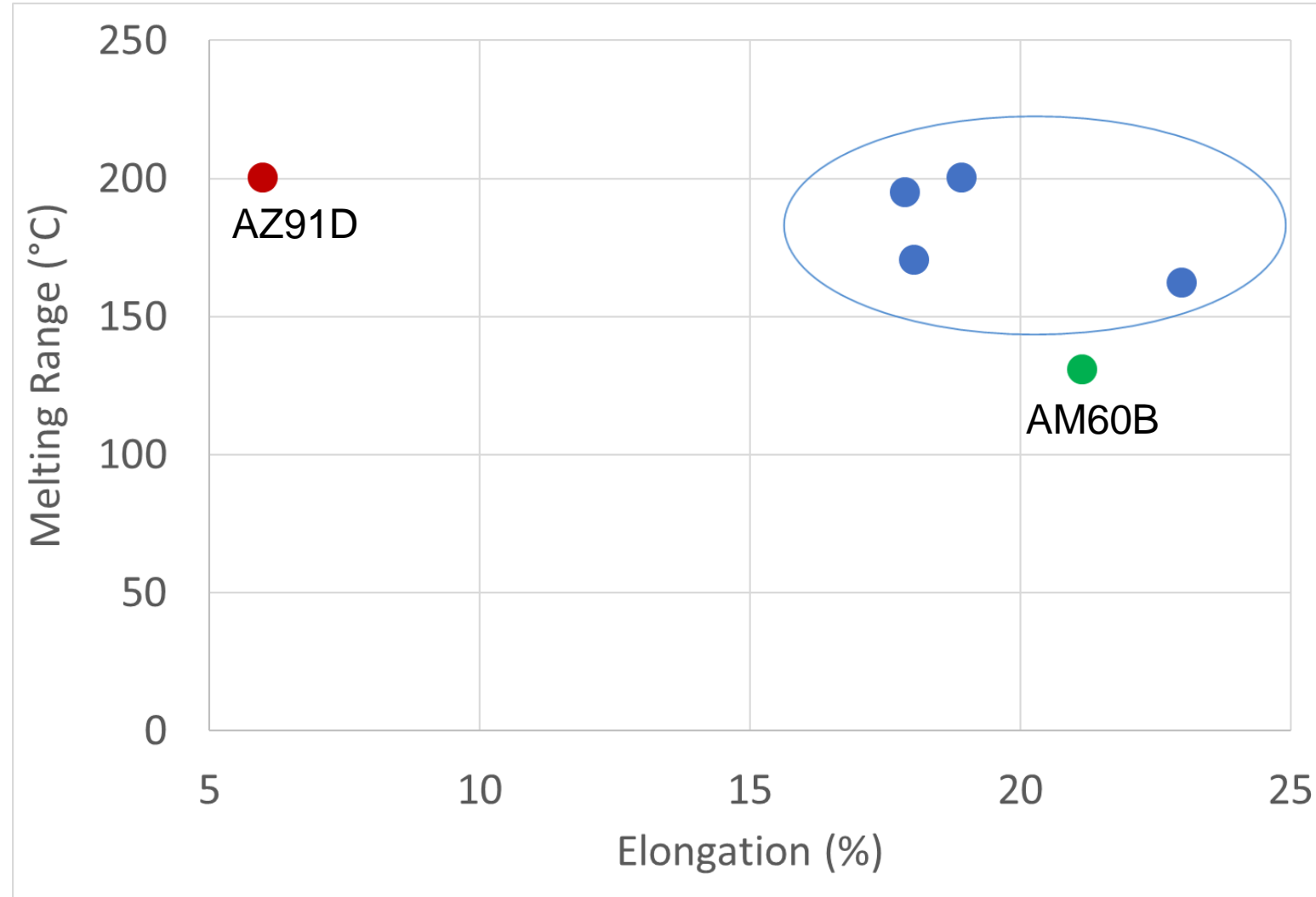


DSC Results



Reasonable agreement was obtained for AM60B

New Alloys With Improved Melting Range, and Required Ductility Have Been Identified



Response to Reviewers Comments

- Project was not reviewed last year.

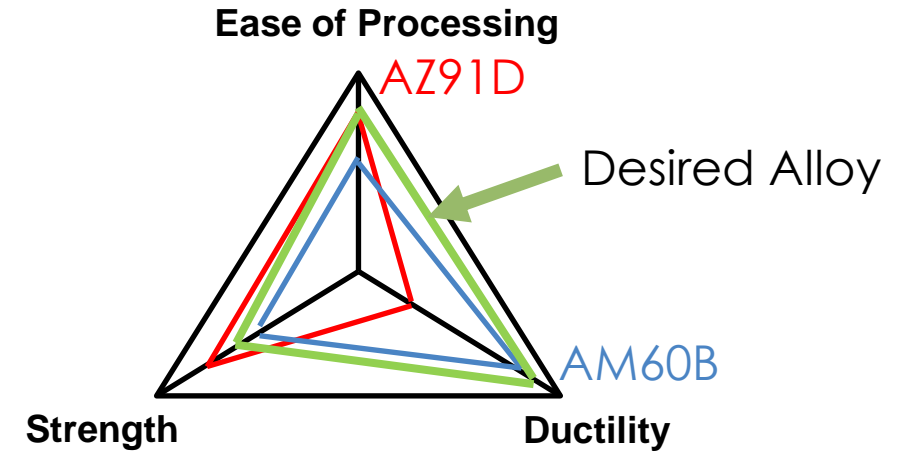
Collaborations and Coordination with Other Institutions

- **Oak Ridge National laboratory: National Laboratory partner**
 - Evaluate microstructure and properties of base alloy obtained from component
 - Computational development of new alloys
 - Alloy property data development
 - Assist in process development
 - Evaluate properties of new alloy obtained from prototype component
- **FCA US LLC (Stellantis): Project Lead**
 - Provide guidance on property requirements
 - Lead down-selection of alloy, ingot and chip production
 - Corrosion testing
 - CAE card development
 - Prototype component design and evaluation
- **Leggera Technologies:**
 - Provide guidance on values of important process variables
 - Provide baseline component for evaluation
 - Supply baseline material for evaluation and alloy development
 - Supply tooling and develop process for manufacturing prototype component using novel alloy
 - Manufacture prototype component

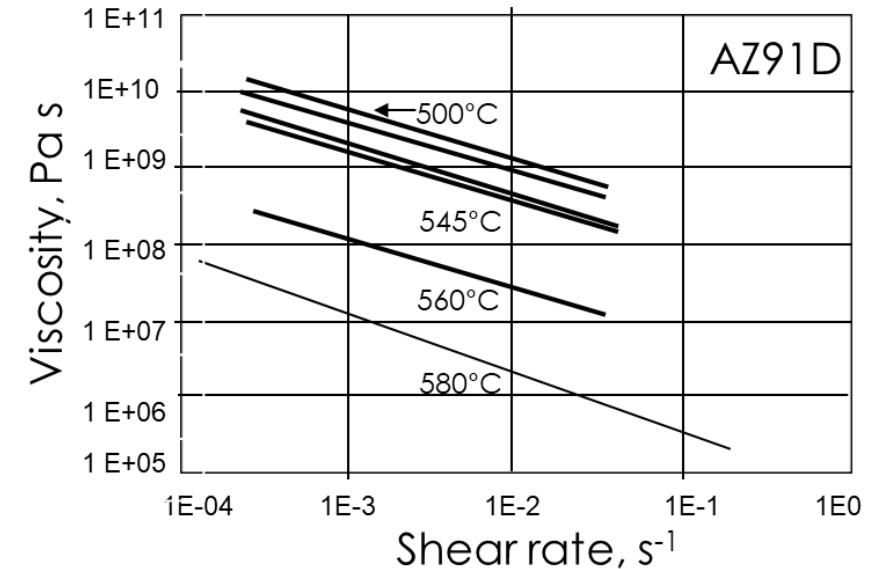


Remaining Challenges and Barriers

- Final down-selection of alloy/s which balance strength, ductility, and ease of processing must be completed
- Processing parameters must be developed for manufacturing tire carrier using new alloy based upon modeling and experiments
 - Determine appropriate injection temperature, and shear rate
- Corrosion behavior of alloy must be shown to be comparable to or better than baseline (AM60B)



Viscosity decreases with increasing shear rate and increasing temperatures*



*Adapter from F. Czerwinski, Magnesium Injection Molding, Springer, 2008

Proposed Future Research

- Corrosion Testing at Stellantis
 - ASTM G85 Annex 2 is a cyclic acidified salt spray test, target duration is based on 10-year service
- Final alloy down-selection based upon DSC results, tensile testing, and microstructure evaluation
- Ingot and chip fabrication
- Prototype component fabrication at Leggera Technologies
- Analysis of prototype component at Stellantis and ORNL



(1) Mg alloy with standard pre-treatment and powder coat (2) Hem adhesive, (3) aluminum sheet and e-coat



Prototype Wrangler Spare Tire Carrier
(Thixomolded® New Alloy)
Improved ductility / fracture resistance

Summary

- **Relevance:**
 - Reducing the weight of a conventional passenger car, battery electric and heavy-duty vehicles by 10% using lightweight Mg alloy components will result in a 6%–8% improvement in fuel economy
 - Thixomolded components have finer grain size, higher ductility, and lower porosity than die cast components
- **Approach/Strategy:**
 - Existing die cast alloys are not ideally suited for thixomolding® process
 - Alloys with optimum combination of ease of processing, strength, and ductility are needed
- **Accomplishments:**
 - New alloys with wider melting range and good mechanical properties have been identified using computational modeling and laboratory scale heats
- **Collaborations:**
 - This work is a CRADA between Oak Ridge National Laboratory, Stellantis, and Legerra Technologies
- **Proposed Future Work:**
 - Prototype spare tire carrier will be thixomolded® using one new alloy and will be evaluated